



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

TUTORIAL ON GASIFICATION

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Problem 1.

A MSW has the following composition on mass basis:

C: 37.5 (%), H: 8.8 %, O: 27.6 %, N:0.40 %, S:0.10 %, Moisture: 20.5% and Ash:5.1%.

Determine the molecular formula and heating value of the MSW using the following relation

$$\text{HHV in MJ/Kg} = 0.3516 * \text{C} + 1.16225 * \text{H} - 0.1109 * \text{O} + 0.0628 * \text{N} + 0.10465 * \text{S}$$

If the above waste material is gasified in a fluidized bed gasifier, what will be the composition of syngas when waste to oxygen ratio is maintained as 0.8 (mass/mass) and steam to MSW ratio is also maintained as 0.1 (mass /mass). Assume CO : H₂ ratio in syngas as 2:1 (vol/vol). Ignore the presence of other impurities and consider the molecular weight of the ash as 56.

Also calculate the yield of H₂ and CO. Why the CO and H₂ content is so low? How it can be improved?

Ans.	Basis = 100 g MSW	Amount of elements
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Composition of the MSW

C: 37.5 %,
 H: 8.8 %,
 O: 27.6 %,
 N:0.40 %,
 S:0.10%,
 Moisture: 20.5%
 Ash: 5.1%
 Total = 100

C: $37.5 \text{ g} = 37.5/12 = 3.125 \text{ moles}$
 H: $8.8 \text{ g} = 8.8/1 = 8.8 \text{ moles}$
 O: $27.6 \text{ g} = 27.6/16 = 1.725 \text{ moles}$
 N: $0.40 \text{ g} = 0.4/14 = 0.0286 \text{ moles}$
 S: $0.10 \text{ g} = 0.10/32 = 0.0031 \text{ moles}$
 Moisture: $20.5 \text{ g} = 20.5/18 = 1.139 \text{ moles}$
 Ash: $5.1 \text{ g} = 5.1/56 = 0.091 \text{ moles}$
 O from moisture (H_2O) = 1.139 moles
 H from moisture (H_2O) = $2 \times 1.139 = 2.278 \text{ moles}$

Molecular formula $\text{C}_{3.125} \text{H}_{8.8} \text{O}_{1.725} \text{N}_{0.0286} \text{S}_{0.0031} \text{Ash}_{0.091} (\text{H}_2\text{O})_{1.139}$

Or $\text{C}_{3.125} \text{H}_{11.078} \text{O}_{2.864} \text{N}_{0.0286} \text{S}_{0.0031} \text{Ash}_{0.091}$

Composition on dry and ash free basis

$$C: 37.5 * 100 / (100 - 20.5 - 5.1) = 50.4 \%$$

$$H: 8.8 * 100 / (100 - 20.5 - 5.1) = 11.83 \%,$$

$$O: 27.6 * 100 / (100 - 20.5 - 5.1) = 37.10 \%,$$

$$N: 0.40 * 100 / (100 - 20.5 - 5.1) = 0.54 \%,$$

$$S: 0.10 * 100 / (100 - 20.5 - 5.1) = 0.13 \%,$$

Now HHV can be calculate as follows

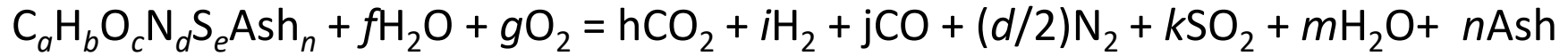
$$HHV = 0.3516 * C + 1.16225 * H - 0.1109 * O + 0.0628 * N + 0.10465 * S$$

$$\begin{aligned} HHV &= 0.3516 * 50.4 + 1.16225 * 11.83 - \\ &0.1109 * 37.10 + 0.0628 * 0.54 + \\ &0.10465 * 0.13 \\ &= 27.40 \text{ MJ/Kg (Dry and ash free basis)} \end{aligned}$$

$$\begin{aligned} HHV &= 0.3516 * 37.5 + 1.16225 * 8.8 - 0.1109 * 27.6 + 0.0628 * 0.4 + 0.10465 * 0.1 \\ &= 20.387 \text{ MJ/kg (wet basis)} \end{aligned}$$



Let us assume the combustion reaction as follows



Molecular formula of the MSW is $C_{3.125}H_{11.078}O_{2.864}N_{0.0286}S_{0.0031}\text{Ash}_{0.091}$

By component mass balance

$$a = h + j = 3.125$$

$$b + 2f = 2i + 2m$$

$$c + f + 2g = 2h + j + 2k + m$$

$$d = 0.0286$$

$$e = k = 0.0031$$

$$n = 0.091$$

Molecular weight of the MSW

$$3.125 \times 12 + 11.078 \times 1 + 2.864 \times 16 + 0.0286 \times 14 \\ + 0.0031 \times 32 + 0.091 \times 54 = 99.8156 \text{ g}$$

Mass of MSW / mass of $O_2 = 0.8$

Therefore, mass of O_2 used per mole of MSW
is $99.8156 / 0.8 = 124.77 \text{ g} = 3.899 \text{ moles}$

Hence moles of oxygen used per mole of MSW =
 $g = 3.899 \text{ moles}$

Mass of steam/ mass of MSW = 0.1 (Given)

H_2O used during gasification = $0.1 * 99.8156 \text{ g} = 9.9815 \text{ g} = 0.555 \text{ moles}$

$$f = 0.555$$

$$h + j = 3.125$$

$$11.078 + 2*0.555 = 2i + 2m \longrightarrow 11.078 + 2*0.555 = 2i + 2m = 12.188$$

$$i + m = 6.094 \text{ (A)}$$

$$2.864 + 0.555 + 2*3.899 = 2h + j + 2*0.0031 + m$$

$$j = 2i \text{ (Given)}$$

$$h + j = 3.125 \quad h + 2i = 3.125 \text{ (B)}$$

$$\text{So, } 2.864 + 0.555 + 2*3.899 = 2h + 2i + 2*0.0031 + m = 11.217$$

$$2h + 2i + m = 11.217 - 2*0.0031 = 11.211 \text{ (C)}$$

Now by (C) - (B) we get $2h + 2i + m - h - 2i = 11.211 - 3.125$ Or $h + m = 8.086$ (D)

Again by (D) - (A), we get $h + m - i - m = 8.088 - 6.094$ Or $h - i = 1.994$ (E)

Now by $2 \times \text{E} + \text{(B)}$ we get $2h - 2i + h + 2i = 2 \times 1.994 + 3.125$ Or $3h = 7.113$ Or $h = 2.37$ (F)

Putting the value of h in (B) we get $h + 2i = 3.125$ Or $2i = 3.125 - 2.37 = 0.754$

From (G) and (A) $m = 6.094 - 0.337 = 5.717$ Or $i = 0.377$ (G)

Therefore , Composition of syngas is

$\text{CO}_2 = 2.37$ mole

$\text{H}_2 = 0.377$ moles

$\text{CO} = 0.754$ moles

$\text{N}_2 = 0.0286/2 = 0.0143$ moles

$\text{SO}_2 = 0.0031$ moles

$\text{H}_2\text{O} = 5.717$ moles

Total moles = 9.2354 moles

Therefore , Composition of syngas in vol %

$\text{CO}_2 = 2.37 \times 100 / 9.2354 = 25.66 \%$

$\text{H}_2 = 0.377 \times 100 / 9.2354 = 4.1 \%$

$\text{CO} = 0.754 \times 100 / 9.2354 = 8.2 \%$

$\text{N}_2 = 0.0143 \times 100 / 9.2354 = 0.155 \%$

$\text{SO}_2 = 0.0031 \times 100 / 9.2354 = 0.034 \%$

$\text{H}_2\text{O} = 5.717 \times 100 / 9.2354 = 61.90 \%$

We know that

$$H_2 \text{ yield} = \frac{H \text{ atoms in the syngas}}{H \text{ atoms injected}}$$

$$CO \text{ yield} = \frac{C \text{ atoms in the formed CO}}{C \text{ atoms injected}}$$

$$C \text{ atoms in the formed CO} = j = 0.754$$

$$C \text{ atoms in feed} = a = 3.125$$

$$CO \text{ yield} = 0.754/3.125 = 0.241$$

$$\text{Hydrogen atom in syngas} = 2i = 0.754$$

$$\text{Hydrogen atom in feed} = b = 11.078$$

$$\text{Hydrogen yield} = 0.754 / 11.078 \\ = 0.068$$

The CO and H₂ content is low because more oxygen (O₂/ MSW = 1/0.8 = 1.25) is used

Reducing the O₂/ MSW ratio as well as providing less steam the CO and H₂ content in syngas can be increased.

Problem 2

In an MSW gasifier air flowrate and feed flow rate are $10\text{Nm}^3/\text{s}$ and 8 kg per second respectively. The MSW does not contain any sulphur, nitrogen and chloride. The syngas contains CO (40%) , CO_2 (2 %), H_2 (30%), CH_4 (5%) and C_2H_2 (2%). Calculate the rate of production of syngas in Nm^3/kg of MSW.

Solution

We know that under the above condition the rate of syngas production can be computed by the following equation

$$\text{Fuel gas production}(\text{Nm}^3.\text{kg}^{-1}) = \frac{\text{air flow rate}(\text{Nm}^3.\text{s}^{-1}) \times 0.79}{\left[1 - \frac{\text{CO} + \text{CO}_2 + \text{H}_2 + \text{CH}_4 + \text{C}_2\text{H}_2}{100}\right]} \times \text{feeding rate}(\text{kg}.\text{s}^{-1})$$

Therefore,

$$\text{Synags production} = [(10*(0.79))/[(1-(0.4 + 0.02 + 0.3 + 0.05 + 0.02))]*8$$

$$= 7.9/(0.21*8)= 4.702 \text{ Nm}^3/\text{kg MSW}$$



Thanks...

